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The End of the Lines for OX 169: No Binary Broad-Line Region

J. P. Halpern[1]
Astronomy Department, Columbia University, 550 West 120th Street, New York, NY 10027

and

M. Eracleous[1]
Department of Astronomy and Astrophysics, The Pennsylvania State University,
525 Davey Laboratory, University Park, PA 16802

ABSTRACT

We show that unusual Balmer emission line profiles of the quasar OX 169, frequently described as either self-absorbed or double peaked, are actually neither. The effect is an illusion resulting from two coincidences. First, the forbidden lines are quite strong and broad. Consequently, the [N II] λ6583 line and the associated narrow-line component of Hα present the appearance of twin Hα peaks. Second, the redshift of 0.2110 brings Hβ into coincidence with Na I D at zero redshift, and ISM absorption in Na I D divides the Hβ emission line. In spectra obtained over the past decade, we see no substantial change in the character of the line profiles, and no indication of intrinsic double-peaked structure. The Hγ, Mg II, and Lyα emission lines are single peaked, and all of the emission-line redshifts are consistent once they are correctly attributed to their permitted and forbidden-line identifications. A systematic shift of up to 700 km s^{-1} between broad and narrow lines is seen, but such differences are common, and could be due to gravitational and transverse redshift in a low-inclination disk. Stockton & Farnham (1991) had called attention to an apparent tidal tail in the host galaxy of OX 169, and speculated that a recent merger had supplied the nucleus with a coalescing pair of black holes which was now revealing its existence in the form of two physically distinct broad-line regions. Although there is no longer any evidence for two broad emission-line regions in OX 169, binary black holes should form frequently in galaxy mergers, and it is still worthwhile to monitor the radial velocities of emission lines which could supply evidence of their existence in certain objects.

Subject headings: quasars: absorption lines — quasars: emission lines — quasars: individual (OX 169)

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[1]Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.

1. Introduction

The quasar OX 169 is a compact radio source (Gower & Hutchings 1984) as well as a source of curious optical emission lines, the nature of which has been the subject of interesting speculation for 20 years. Smith (1980) first noted the presence of apparent "self-absorption" in the Balmer lines of OX 169 which, if correct as a physical description, would be highly unusual for non-resonance lines. Gaskell (1981) preferred an alternative explanation based on displaced velocities in which the broad and narrow-line regions differ by 1200 km s^{-1}. Ten years later, Stockton and Farnham (1991, hereafter SF) interpreted variability of the Hβ line profile as evidence for two distinct *broad* peaks, thus assigning OX 169 to the family of double-peaked emitters (e.g., Chen & Halpern 1989; Eracleous & Halpern 1994) whose origin remains a subject of intense study. SF discussed both accretion-disk and binary broad-line region (BLR) models, but settled on the binary explanation as more consistent with the nature of the variability (actually, only the difference between two spectra), and the one in their estimation to be the most likely to account for the range of double-peaked behavior seen up to that time in active galaxies in general. Of considerable interest was the connection made by SF between their emission-line evidence for a binary black hole, and an apparent tidal tail in the host galaxy which they showed had the spectrum of starlight. To the extent that black holes are thought to be common in galactic nuclei, and in view of the appearance of OX 169 as a recent merger, SF speculated that a bound pair of black holes had formed, and was now revealing its existence in the form of two distinct BLRs. In this interpretation, it was *assumed* that a pair of supermassive black holes can maintain physically distinct BLRs that appear to the observer sufficiently separated in velocity.

In this paper, we re-evaluate these interesting suggestions about OX 169 using an extensive set of optical spectra obtained over the past decade, as well as archival ultraviolet spectra from the *Hubble Space Telescope* (*HST*). Our conclusion is that there is little if any spectroscopic evidence for a binary BLR in OX 169. In addition to revising the observational description of the broad emission lines from double peaked to single peaked, we discuss how line-profile variability figured into previous interpretations, how our understanding of line-profile variability has developed over the past decade, and what lines of investigation remain to be pursued in this subject.

2. Observations

We obtained many spectra of OX 169 over the past 10 years, with resolution in the range 4–12 Å. Most of these covered the Hβ and Hα emission lines only, although Hγ and Mg II were each observed once. A log of the spectroscopic observations is given in Table 1. Reductions were performed using standard techniques. Of particular relevance to this study is the accuracy of the wavelength calibration, which is typically better than 1/20th of the resolution as determined by the dispersion in the fits to the arc lines. Wavelength calibrations were taken immediately after each object exposure. Slit widths were in the range $1.''7 - 2.''0$, and depending upon seeing and

guiding, placement of the object within the slit can be the dominant source of systematic error in wavelength. The dispersion among measurements of the stronger lines in different spectra of OX 169 is approximately 1 Å, which we interpret as a systematic uncertainty of ≈ 50 km s^{-1} in velocity. Our observational technique was not designed to achieve photometric precision in flux. Instead, we rely on assumed constancy of the [O III] $\lambda 5007$ line wherever possible to standardize the flux.

We also make use of archival (*HST*) spectra of OX 169 obtained in 1992 with the Faint Object Spectrograph (FOS) gratings G130H, G190H, and G270H. These were initially reported by Diplas et al. (1993). Details of the FOS spectra are also given in Table 1.

2.1. Narrow Emission Lines

We begin by assessing the "systemic" redshift of OX 169 as defined by its low-ionization forbidden lines and narrow components of its Balmer lines. Figure 1 shows a montage of spectra around the Hα line. Dashed lines indicate the wavelengths of Hα, [N II] $\lambda\lambda 6548,6583$, and [S II] $\lambda\lambda 6716,6730$ for a best-fitting redshift of 0.21103 ± 0.00013. Of particular importance is the weak but clearly present [S II] doublet at the same redshift as Hα and [N II]. The [S II] lines are so broad as to be almost completely blended, but it is clear that all of the emission-line peaks can be attributed to the narrow components, either Hα or forbidden lines, at a single redshift. We also measured the [O II] $\lambda 3727$ redshift in the 1998 June spectrum, which gave $z = 0.21096$, consistent with the other low-ionization lines. We therefore adopt $z = 0.21103 \pm 0.00013$ as the systemic (low-ionization) redshift.

Next, we turn to the region around Hβ. In Figure 2, we draw dashed lines at the low-ionization redshift of 0.21103 to see how well this agrees with [O III] and Hβ. The agreement with [O III] is very good. Although [O III] prefers a slightly lower redshift of 0.21063 ± 0.00016, the corresponding difference of only ≈ 100 km s^{-1} between high- and low-ionization forbidden lines is common. This comparison assures us that we have correctly identified the peaks on the Hα line with their narrow-line region components. It is difficult to evaluate the agreement with narrow Hβ, predicted to fall at 5887 Å, because, as we shall see, it nearly coincides with with Na I D absorption in our Galaxy's interstellar medium (ISM). In any case, it is clear that the large velocity widths of the strong narrow emission lines, FWHM = 700 km s^{-1} and FWZI = 2500 km s^{-1} as exemplified by [O III], have confused previous interpretations of the broad Balmer-line profiles in OX 169.

2.2. ISM Absorption Lines

In Figure 2, we also draw dotted lines at the wavelengths of Na I $\lambda\lambda 5890,5896$ at zero velocity. It is evident that Na I D absorption is present near the peak of the broad Hβ line, and that this absorption is responsible for the peculiar appearance of Hβ that has been noted by previous

authors. The explanation of this feature as interstellar Na I D absorption fits the data in striking detail. The doublet is resolved in the spectra of highest resolution, particularly from the KPNO 2.1m, and the wavelengths of the pair fall exactly at zero velocity. It is difficult to measure the absorption-line equivalent widths exactly because they are superposed on the peak of an emission line which is a composite of a narrow and broad component. Our best estimate, fitting a Gaussian to the peak of the broad emission line, yields an equivalent width of about 0.6 Å for each of the D_1 and D_2 lines.

We do not regard any other explanations of this doublet as plausible. For example, it is not reasonable to suppose that there is a central reversal consisting of a narrow component of Hβ emission inside a self-absorbed or double-peaked broad emission line. This would require narrow Hβ to be redshifted by ≈ 300 km s^{-1} with respect to narrow Hα and the low-ionization forbidden lines, all of which agree internally to an accuracy of about 50 km s^{-1}. There is also no evidence that Na I D emission from the night sky is contaminating these spectra. The accuracy of our sky subtraction is evidently very good, given the detailed reproducibility among the many spectra in this region and the lack of any systematic problems with other night-sky emission lines that are stronger than Na I D, such as [O I] λ5577 and [O I] λ6300. SF were also careful to rule out the possibility of errors in sky subtraction in their spectra, but they did not consider the possibility of interstellar Na I D absorption which, of course, persists after accurate subtraction of the night-sky emission.

Additional interstellar absorption lines whose equivalent widths are known to correlate with that of Na I D are present in the spectrum of OX 169. These are shown in Figures 3 and 4. The 1996 Lick spectrum covers the region of Ca II H & K ($\lambda\lambda$3968.5,3933.7), which have equivalent widths of 0.14 Å and 0.30 Å, respectively. As shown by the correlations presented in Hobbs (1974), the Ca II and Na I D absorption-line strengths are consistent with the moderate H I column at these coordinates ($\ell, b = 72.^\circ116, -26.^\circ084$) of 8.2×10^{20} cm^{-2} (Stark et al. 1992), and with the extinction $E(B-V) = 0.111$ estimated from *IRAS* 100 μm maps (Schlegel, Finkbeiner, & Davis 1998). In the *HST* spectrum, the Mg II $\lambda\lambda$2795.5,2802.7 doublet is strong, with equivalent widths of 1.57 and 1.03 Å, respectively, and Fe II, Mn II, and Mg I absorption lines are present as well. All of these features support the hypothesis that a modest interstellar Na I D absorption is to blame for the peculiar appearance the Hβ emission line in OX 169.

2.3. Broad Emission Lines

The shapes of the broad emission lines in OX 169 are certainly quite varied. Figure 5 shows examples of all of the broad emission lines that can be extracted from our optical spectra, as well as from the *HST* spectra. The chosen zero velocity point corresponds to the narrow-line redshift of 0.21103. It is interesting that narrow Lyα absorption is present at exactly this redshift, which is presumably the systemic redshift of the host galaxy. The peak of Lyα emission, however, is at $z = 0.21334$, which is redshifted by ≈ 570 km s^{-1} from the narrow lines. The other broad emission

lines are also redshifted, by up to ≈ 700 km s^{-1} as determined by Gaussian fits. Table 2 lists all of the broad emission-line widths and shifts from the spectra illustrated in Figure 5. In addition to this first-order characterization, there are complicating features in some of the line profiles, such as an extended red wing on Hβ which may be due in part to Fe II $\lambda\lambda$4923,5018. Supporting this interpretation are the appearance of broad Fe II multiplets around 4570 Å and 5250 Å, and the fact that such an extended wing is not present in Hα. Hγ may contain a weak contribution from [O III] λ4363, which could have contributed to the double-peaked appearance of this line in previous studies. Broad wings are present on Lyα, but its red wing may also contain a contribution from N V λ1240.

The C IV and C III] line profiles are noisy, and difficult to characterize. Partly inspired by the previous reports of double-peaked Balmer lines in OX 169, Marziani et al. (1996) wrote that the C IV line is probably double-peaked, although the evidence was not strong in their view. We also note that the apparent associated C IV absorption feature at -500 km s^{-1} is not highly significant, and it may be an intrumental artifact because it is narrower than the resolution. The C III] λ1909 line is difficult to interpret because it is likely that a contribution from Si III] λ1892 is present, as well as lines of the Fe III multiplet UV34. Aoki & Yoshida (1998) and Wills et al. (1999) show that Si III] λ1892 typically contributes 20–30% of the flux in this blend, and there is some evidence for such a contribution in Figure 5.

In summary, there are small shifts between the broad-line and narrow-line velocities, as well as differences among the broad-line profiles themselves. These effects are well known among quasars. However, there is no evidence for a two-component broad-line region, or self-absorption in any of the non-resonance lines. After 10 years of monitoring OX 169, we consider that a double-peaked description of its broad emission lines is pretty much ruled out.

3. Discussion

As it turns out, previous descriptions of the spectrum of OX 169 each had some element of truth, but were misled by one or more effects. There *is* absorption in the Hβ line (Smith 1980), but it is caused by Na I in the Galaxy's ISM. The BLR *is* redshifted from the narrow-lines, not by 1200 km s^{-1} as claimed by Gaskell (1981), but by 300–700 km s^{-1}. SF rejected both of these scenarios, and discussed either a double-peaked accretion disk line profile, or a binary BLR. The principal argument that SF developed in favor of a binary BLR employed line-profile variability, which they interpreted as independent behavior of a blueshifted and redshifted line component. Although our own spectra do not support such a description, the spectra of SF, particularly before 1989, remain as evidence that is independent of ours. Therefore, for completeness, we explore the arguments by which their spectra were interpreted, and review what has been learned about variability of double-peaked emitters in the past decade.

3.1. Tests of the Binary BLR Hypothesis

Actually, the variability studied by SF was limited to just two spectra of Hβ, taken in 1983 and 1989. The assumption behind the analysis of SF is that, when a line shape changes, the profile can be uniquely decomposed by differencing into two components, a variable part and a constant part. The resulting pair of line profiles were in turn attributed to two spatially separated sources. In our opinion, it is doubtful that a reliable interpretation of variability can be extracted from just two spectra. In this particular case, it is also important to evaluate the assumptions behind the method. As SF state, for their procedure to have meaning, the light-travel time across the broad-line region must be short compared to the time scale of variability of the photoionizing continuum. A pair of additional requirements that were *not* stated are 1) that each variable photoionizing source does not affect the other's emission-line region, and 2) that variability of a photoionizing source is the *only* mechanism of line profile variability. But all of these requirements together amount to *assuming* most of the properties of the desired solution, namely, that a pair of photoionizing sources are associated with spatially distinct BLRs which have stationary velocity fields and are immune from the effects of each other's radiation. It does not seem possible that a single difference spectrum could be used to justify all of the required assumptions without employing a circular argument.

A number of intensive monitoring programs have been conducted over the past decade which bear upon these issues. First, a sensitive search for the smoking gun of the binary BLR model in three bona fide double-peaked emitters yielded interesting but null results (Eracleous et al. 1997). The absence of long-term, systematic velocity variations characteristic of a double-lined spectroscopic binary effectively ruled out the binary BLR model for all reasonable black hole masses in Arp 102B, 3C 390.3, and 3C 332. The factor which makes this test feasible in a reasonable period of time is a large velocity separation of the emission-line peaks. The observed *absence* of radial velocity variations can be translated into a lower limit on the mass of the assumed binary,

$$M \ > \ 4.7\times10^{8}\,(1+q)^{3}\left(\frac{P}{100\,\mathrm{yr}}\right)\left(\frac{v_1\sin i}{5000\ \mathrm{km\,s^{-1}}}\right)^{3}\ M_{\odot}, \tag{1}$$

where $M = M_1 + M_2$, $q = M_1/M_2$, P is an observed lower limit on the orbital period, and $v_1 \sin i$ is the observed radial velocity of M_1. Since the mass depends on the cube of the velocity, those line profiles with peaks that are displaced by 5,000 km s^{-1} or more can provide a very sensitive test of the hypothesis in a couple of decades. Eracleous et al. (1997) eliminated all binary masses less than $10^{10}\,M_{\odot}$ in Arp 102B, 3C 390.3, and 3C 332. A previous analysis of Gaskell (1996), which found striking evidence for a radial velocity drift and thus binary orbital motion in 3C 390.3, was contradicted by the longer time span of the observations made by Eracleous et al. (1997) in which the trend did not continue as expected for a spectroscopic binary.

This demonstrated absence of binary BLRs in those three objects implies that there must be a mechanism by which a single black hole can produce a double-peaked emission line, but it does not rule out a scenario in which an unseen black hole perturbs the emission-line velocity of another. However, as can be seen by inverting equation (1) for the orbital period P, it might be difficult

to discover such a single-lined spectroscopic binary in an object like OX 169 for which the radial velocity displacement of the broad emission lines is ≤ 700 km s^{-1}.

3.2. Line-Profile Variability: Dynamics, not Reverberation!

A second major development in the study of emission-line variability is the realization that line-profile variability is not the result of light-echo effects, i.e., reverberation. All of the Seyfert monitoring campaigns have shown that, although the total *intensity* of an emission line is modulated in response to the intensity of the ionizing continuum with a lag of days to months, the *shape* of the line changes hardly, if at all, on these time scales (Ulrich 1991; Wanders & Peterson 1996; Kassebaum et al. 1996). In particular, both sides of the double-peaked emission line in 3C 390.3 respond simultaneously to continuum variations (Dietrich et al. 1998; O'Brien et al. 1998). On the other hand, we have learned that major changes in line shapes on long time scales of years to decades is ubiquitous, especially in double-peaked emitters (Veilleux & Zheng 1991; Newman et al. 1997; Storchi-Bergmann et al. 1995; Gilbert et al. 1998), but that these slow profile variations are not responses to changes in the ionizing continuum. Rather, they must be due to physical changes in the velocity field of the emitting gas, i.e., *dynamical motions.* Some of the most dramatic examples are found in the emergence of new double-peaked broad emission lines in well known objects which had no such component in the past, such as Pictor A (Halpern & Eracleous 1994; Sulentic et al. 1995), M81 (Bower et al. 1996), and NGC 1097 (Storchi-Bergmann, Baldwin, & Wilson 1993).

Much of the recent effort in modeling line-profile variability has focussed on dynamical motions such as hot spots and spiral waves in accretion disks (Zheng, Veilleux, & Grandi 1991; Chakrabarti & Wiita 1994; Newman et al. 1997; Gilbert et al. 1999), tidal disruption of stars, and precessing eccentric accretion disks (Eracleous et al. 1995; Storchi-Bergmann et al. 1997). This is not to say that a universally applicable model of line profile variability is in the offing. On the contrary, it is a warning that one should not expect to extract a dynamical model of a quasar broad-line region from two snapshots of an emission-line profile, or even from a dozen. In all of these studies, the double-peaked line profile is treated as a dynamic whole to be modeled with an evolving velocity field, as there is evidently no simple decomposition of the profile into a pair of independent, stationary entities.

Since much recent modeling involves an accretion-disk origin for the emission-lines, we wish to address here a stock criticism of the accretion-disk hypothesis which seems to persist, unjustifiably in our opinion, and should be put to rest. Several authors have noted that *if* line-profile variability is caused by the response of an axisymmetric accretion disk to a variable central photoionizing source, then the blue and red sides of an emission-line profile should vary in concert (e.g., Miller & Peterson 1990). While this is a valid proposition as far as it goes, recent references to it have omitted the clause beginning with the word *if*, asserting, in effect, that line profile variability *is* caused by reverberation, and that it must therefore be symmetric in a disk model (e.g., Gaskell 1996). Since line-profile variability is generally observed to be asymmetric, disks are disfavored

according to this argument. But as reviewed here, there is now ample evidence that observed line-profile variability has a much longer time scale than can be explained by reverberation, and must therefore be a dynamical effect. On *short* time scales, line peaks *do* vary in concert, and are thus consistent with a disk-like velocity field. While reprocessing undoubtedly plays an important role in explaining the spectra of quasars, we would do well to remember that not all variability must or can be attributed to reprocessing, and this appears especially to be the case for emission-line profiles.

3.3. Accretion-Disk Emission Revisited

The question then arises, is there anything of general interest to be learned from the broad emission lines in OX 169? Having patiently collected data for 10 years, we feel the obligation to engage in at least some speculation of our own. Since we have argued that the principal characteristics of the broad lines are 1) a slight redshift with respect to the narrow lines, and 2) differences among their widths, it would appear that the most natural location for their origin would be on the surface of an accretion disk (the second-best hypothesis according to SF). The redshifts can be understood as the combined effect of gravitational and transverse redshift on circular motion viewed close to the rotation axis. The net redshift Δv in the weak-field limit is simply $\Delta v/c \approx (3/2)\,(r_{\rm g}/r)$, where r is the orbital radius and $r_{\rm g}$ is the gravitational radius GM/c^2. The line width v is dominated by the longitudinal Doppler shift, such that $v/c \approx (r_g/r)^{1/2}\,\sin i$. For example, since we measure for the Hγ line in OX 169 $\Delta v \approx 730$ km s^{-1} and $v \approx 4500$ km s^{-1}, we estimate crudely that $r \approx 620\, r_{\rm g}$ and $i \approx 22^\circ$. Such mild relativistic effects have long been hypothesized to explain such asymmetries that are generally found in emission-line profiles (e.g., Corbin 1997).

As mentioned by SF, the photoionization models of Dumont & Collin-Souffrin (1990a,b), in which a central photoionizing source illuminates the outer accretion disk, naturally produce lines of different widths because the physical conditions vary with radius in the disk. In these calculations, Hα is narrower than Hβ because the lower-order transitions saturate first at high flux levels in the inner disk. Another successful prediction of the model is that Mg II is narrower than Hα. Mg II is preferentially produced in the outer disk where, at low flux levels, it is enhanced over Hα because the lines are formed by recombination and not by collisional excitation. Thus, the trend among the emission-line widths in OX 169 is largely in accord with the disk photoionization model. In addition, the accretion-disk wind model (Chiang & Murray 1996; Murray & Chiang 1997,1998) may well be applicable, and will have additional affects on the emission-line profiles.

Although SF considered the accretion-disk hypothesis in light of a presumed double-peaked emission line, there is no requirement that disk lines be double peaked, as numerous authors, including Dumont & Collin-Souffrin (1990a,b), Jackson, Penston, & Pérez (1991), and Murray & Chiang (1997) have explained. The most extreme of the observed double-peaked emitters may be easiest to *recognize* as disk-like because of the wide separation of their peaks, but this may be the exceptional case that obtains when the ratio of outer to inner radius is small, i.e, only ~ 3.

As the outer radius of the line emitting region increases, the two peaks merge together at small velocity, which may be the more general rule. Radiative transfer effects in the lines also tend to make single-peaked profiles. The small inclination inferred for OX 169 would be consistent with its single-peaked line profiles, and also with its core-dominated radio source.

4. Conclusions and Future Work

We have shown that the Balmer lines in OX 169 are neither self-absorbed nor double peaked. All previous analyses of its spectra were led astray by some combination of the following effects: 1) The forbidden lines of OX 169 are unusually strong and broad, consequently, [N II] λ6583 masquerades as an additional component of Hα. 2) Hβ coincidences with Galactic Na I D absorption, which has an equivalent width similar to the spurious "trough" between Hα and [N II] λ6583. 3) The broad emission lines are redshifted by as much as 700 km s^{-1} from the forbidden lines. In spectra obtained over the past decade, we see no substantial change in the character of the line profiles, and no indication of intrinsic double-peaked structure once the above effects are recognized. In support of this interpretation, we show that 1) the Na I D doublet is resolved in absorption, 2) ISM absorption in Ca II H and K and Mg II are detected at a strength consistent with that of Na I D, 3) the Mg II, Lyα, and H γ emission lines are single peaked, and 4) all of the emission-line redshifts are consistent once they are correctly attributed to their permitted and forbidden-line identifications.

A systematic shift of up to 700 km s^{-1} between broad and narrow lines is seen, but such differences are common and could be due to gravitational and transverse redshift in a disk-like broad-line region viewed at small inclination. The single peaked nature of the emission lines is not an obstacle to a disk model, and may in fact be the general rule, while double-peaked lines are the exception. Long-term variability of the emission-line profiles in OX 169 appears to be modest and unexceptional, and is probably due to dynamical motions. Ultimately, our understanding of why quasars vary will have to involve dynamics.

Stockton & Farnham (1991) interpreted the line profiles of OX 169 in terms of a binary BLR, which was especially intriguing since they also found an apparent tidal tail in the host galaxy, and speculated that a recent merger had supplied the nucleus with a pair of black holes which was now coalescing. Strictly speaking, our revised description of the line profiles is not to be taken as evidence against the *presence* of a binary black hole, but only for the absence of two separate emission-line regions. In view of the mounting evidence for the ubiquity of black holes in galactic nuclei, the formation of binary black holes in galaxy mergers should be relatively common. Such binaries could spend anywhere from $10^8 - 10^{10}$ yr at separations of $0.01 - 0.1$ pc (Begelman et. al 1980), during which their orbital motion might be detected. According to equation (1), it would be worthwhile to monitor emission lines that have peaks displaced by more than 1500 km s^{-1} for evidence of binary motion, especially if such displacements are not easily compatible with gravitational redshift alone, e.g., if they are blueshifted. We have several such candidates under

surveillance. Even if only one emission-line region exists in such a system, the orbital acceleration by the unseen black hole could perturb the emission-line velocities in the manner of a single-lined spectroscopic binary. Such black hole binaries of $M \approx 10^8\, M_\odot$ would undergo detectable orbital motion in just a couple of decades. If these candidates were also compact VLBI radio sources, it would feasible to obtain direct confirmation via proper motion of order microarcseconds per year (Eracleous et al. 1997). Indirect evidence for binary orbital motion may be present in the wiggles of a milliarcsecond radio jet (Kaastra & Roos 1992; Roos, Kaastra, & Hummel 1993).

Unfortunately, OX 169 is no longer a prime candidate for such a monitoring program. Over the past decade its emission lines have revealed little evidence for unusual velocities, and no other peculiarities that inspire thoughts of binarity. Regretfully we opine, this is the end of the lines for OX 169.

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Fig. 1.— Spectra around the Hα line of OX 169 which have been renormalized and shifted vertically for clarity. The dashed lines correspond to the wavelengths expected for [N II] λ6548, Hα, [N II] λ6583, [S II] λ6716, and [S II] λ6730, all at $z = 0.21103$.

Fig. 2.— Spectra around the Hβ line of OX 169 which have been normalized to the flux of [O III]λ5007 and shifted vertically for clarity. The dashed lines correspond to the wavelengths expected for Hβ and [O III] $\lambda\lambda$4959,5007 at $z = 0.21103$. Dotted lines mark the wavelengths of the Na I D doublet at $z = 0$.

Fig. 3.— Ca II H and K absorption from the ISM in the spectrum of OX 169. The H and K equivalent widths are 0.14 Å, and 0.30 Å, respectively.

Fig. 4.— Galactic ISM absorption lines in the *HST* ultraviolet spectrum of OX 169. The expected zero-velocity wavelengths of various absorption lines are indicated, as are their relative oscillator strengths by the vertical length of the tick mark. The equivalent widths of Mg II $\lambda\lambda$2795.5,2802.7 are 1.57 Å, and 1.03 Å, respectively.

Fig. 5.— Broad emission line profiles from the optical and UV spectra of OX 169. Continuum has been subtracted. Zero velocity in this figure corresponds to the narrow-line redshift $z = 0.21103$.

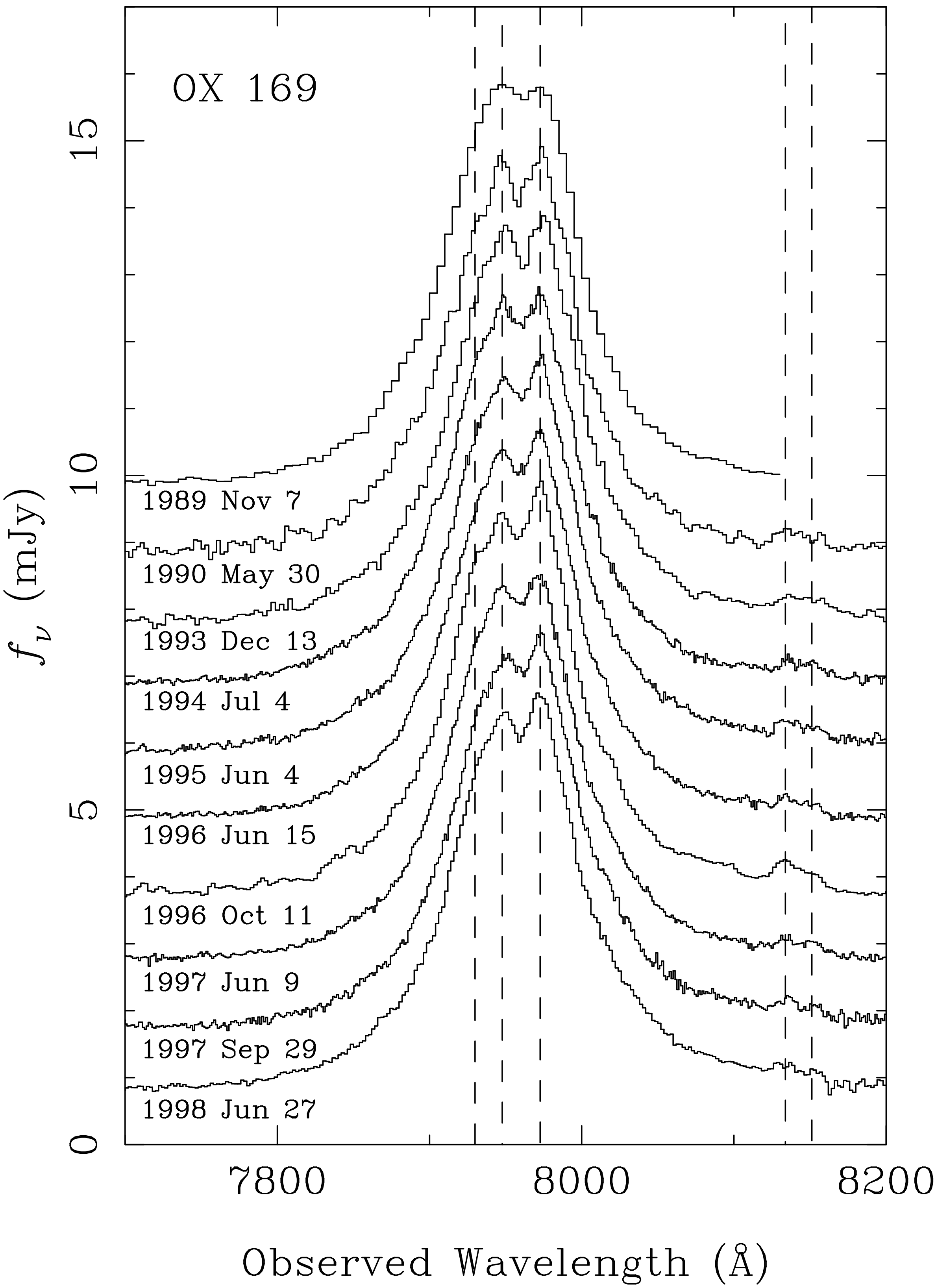
Table 1. Optical and UV Spectroscopy of OX 169.

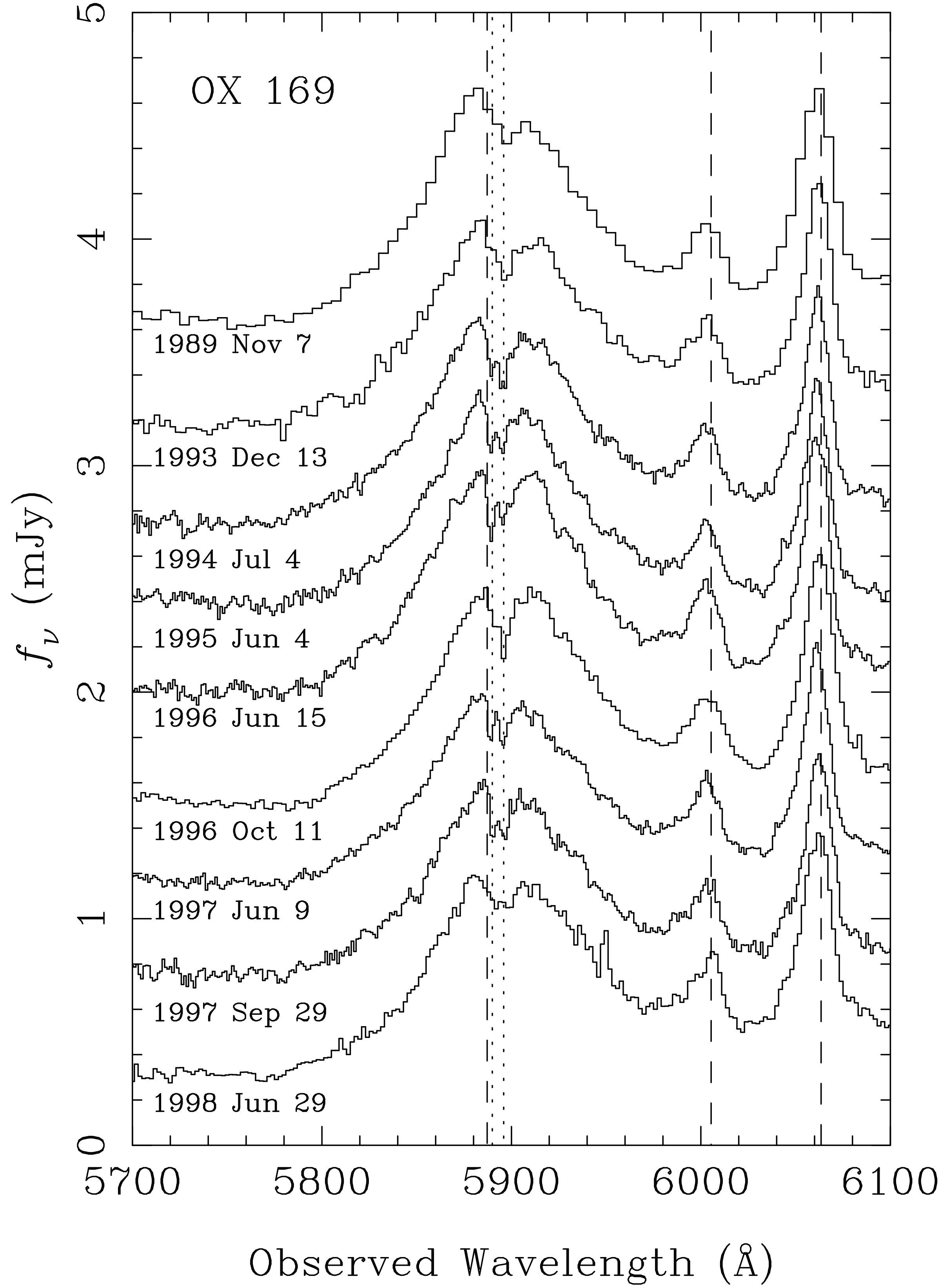
UT Date	Telescope	Exposure time (s)	Wavelength range (Å)	Resolution (Å)
1989 Nov. 7	MDM 2.4m	1800	5300 – 8100	12
1990 May 30	KPNO 2.1m	2700	6300 – 8300	7
1992 Jan. 7	*HST* FOS	2043	1160 – 1600	1
1992 Jan. 7	*HST* FOS	1001	1600 – 2310	1.5
1992 Jan. 7	*HST* FOS	1047	2220 – 3280	2
1993 Dec 13	KPNO 4m	1800	5000 – 9800	8
1994 July 4	KPNO 2.1m	4000	5500 – 8500	4
1995 June 4	KPNO 2.1m	4000	5500 – 8500	4
1996 June 15	KPNO 2.1m	3915	5500 – 8500	4
1996 Oct. 11	Lick 3m	4800	3200 – 4400	5
1996 Oct. 11	Lick 3m	4800	5600 – 8300	5
1997 June 9	KPNO 2.1m	3600	5500 – 8500	4
1997 Sep. 29	KPNO 2.1m	3600	5500 – 8500	4
1998 June 27	MDM 2.4m	3600	6300 – 8300	5
1998 June 29	MDM 2.4m	2500	4400 – 6400	7

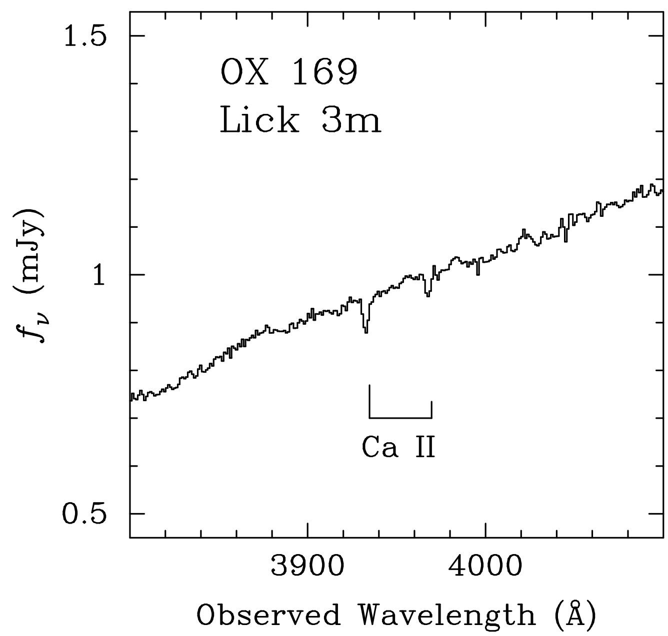
Table 2. Emission-Line Widths and Shifts.

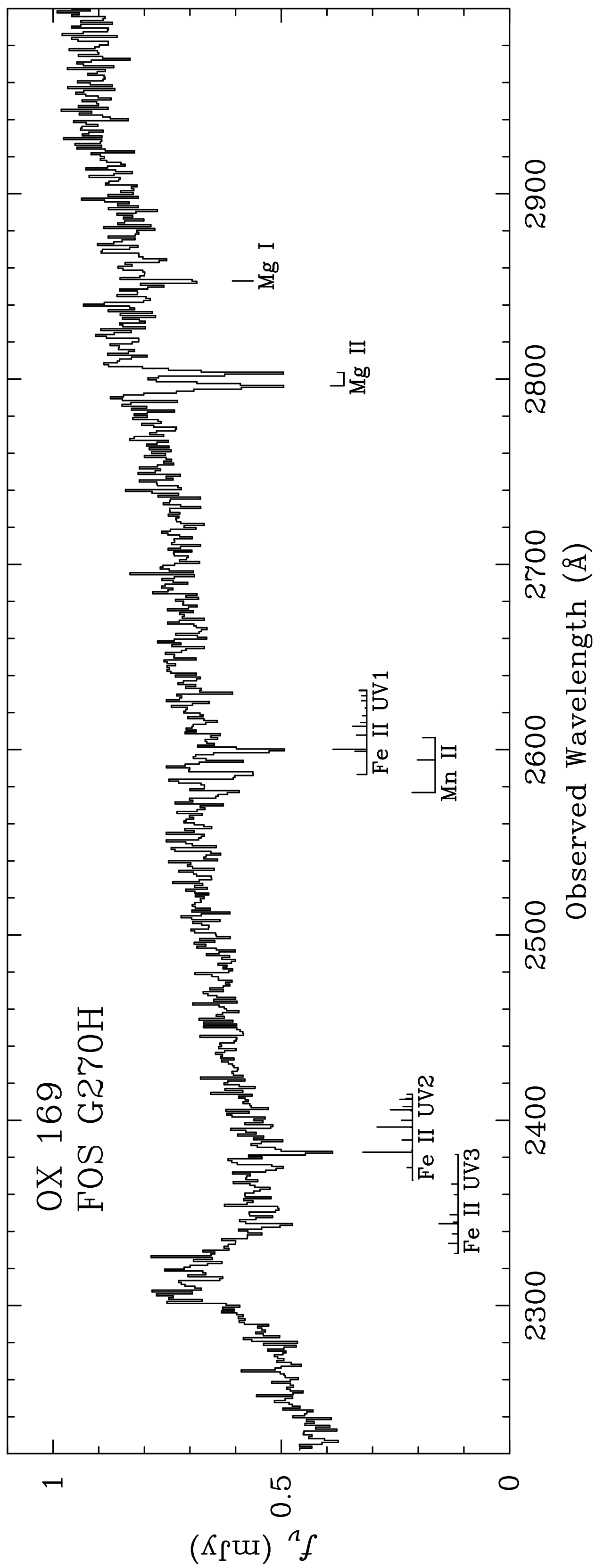
Line Identification	Rest Wavelength (Å)	Measured Wavelength (Å)	Shift[a] ($km\ s^{-1}$)	FWHM ($km\ s^{-1}$)
Hα	6562.79	7956.12	320	3770
Hβ	4861.33	5895.88	440	4550
Hγ	4340.46	5269.20	730	4490
Mg II	2799.07	3397.10	650	2650
C III]	1908.73	2312.18	80	5380
C IV	1549.48	1879.67	30	6930
Lyα	1215.67	1475.02	570	5030

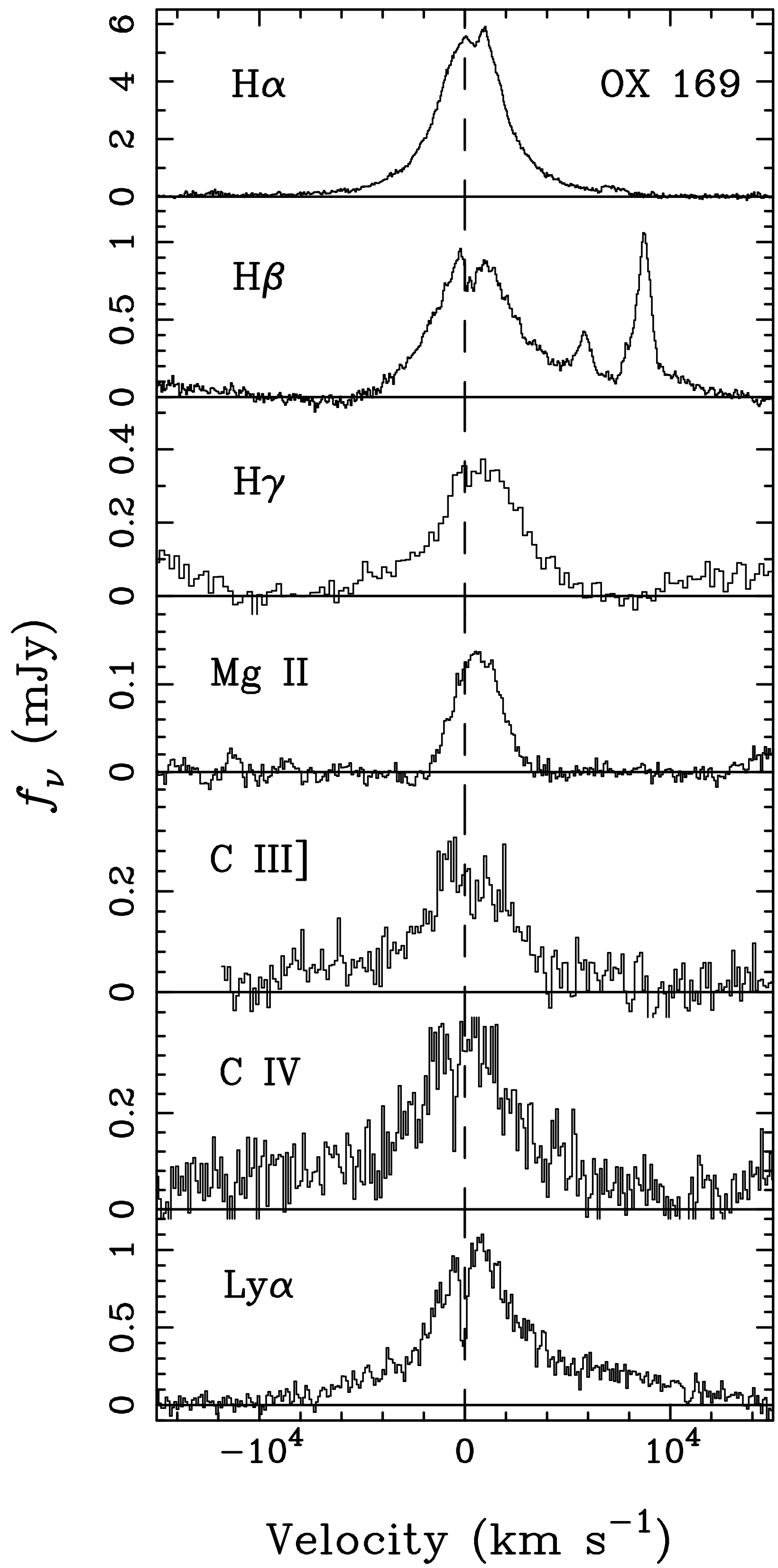
[a] Velocity with respect to the systemic redshift of $z = 0.21103$. Velocities are all positive, therefore redshifted.


OX 169
1989 Nov 7
1990 May 30
1993 Dec 13
1994 Jul 4
1995 Jun 4
1996 Jun 15
1996 Oct 11
1997 Jun 9
1997 Sep 29
1998 Jun 27
f_ν (mJy)
0
5
10
15
7800
8000
8200
Observed Wavelength (Å)


OX 169
1989 Nov 7
1993 Dec 13
1994 Jul 4
1995 Jun 4
1996 Jun 15
1996 Oct 11
1997 Jun 9
1997 Sep 29
1998 Jun 29
f_ν (mJy)
Observed Wavelength (Å)
0
1
2
3
4
5
5700
5800
5900
6000
6100


OX 169
Lick 3m
Ca II
1.5
1
0.5
3900
4000
f_ν (mJy)
Observed Wavelength (Å)


OX 169
FOS G270H
Fe II UV3
Fe II UV2
Fe II UV1
Mn II
Mg II
Mg I
2300
2400
2500
2600
2700
2800
2900
Observed Wavelength (Å)
0
0.5
1
fν (mJy)



Hα
OX 169
Hβ
Hγ
Mg II
C III]
C IV
Lyα
f_ν (mJy)
Velocity (km s^{-1})
0
2
4
6
0
0.5
1
0.2
0.4
0.1
-10^4
10^4